Chapter 28

# A Lucky Ending

I WAS A FEW months over the age of 65, near the canonical age of retirement, when, in October 1980, I stood on the summit of Blaven. More than my project of climbing all the Scottish Munros seemed to be finished. By then, most of my work, excepting that in cosmology, had been decided for better or for worse. Mostly for better, fortunately. The cosmology was otherwise, however, and it is this lingering topic I am going to discuss here in my final chapter.

I will be immodest enough to claim a reasonably substantial role in the rise of big-bang cosmology, which took place in the 1960s, and which is still quoted as the foundation of belief in this theory. In 1963–1964, there was work with Roger Tayler that had the effect of refocussing attention on the achievements, around 1950, of George Gamow and his colleagues. Then, in 1966–1967, there was work done in collaboration with William A. Fowler and Robert V. Wagoner that suggested that the element lithium (or, at any rate, one of its isotopes) was the product of the big bang. Indeed, the latter investigation has served as a springboard for the development of the concept of nonbaryonic "missing mass," which, by 1980, had become all the rage. This was amply sufficient for me to have become one of the dozen or so influential torchbearers for the big-bang theory, after whom the astronomical world in general follows. But it seemed to me, again for better or for worse, that the big-bang theory did not develop, as the years passed, as a successful theory is supposed to do. A successful theory should progress as a river grows, from trickles on numerous hillsides, to a moderate number of tributaries, and then, by amalgamation, into a broad stream. This has not happened with the big bang, which has almost no success to offer in return for a great deal of effort over the past two decades.

Cosmology is the study of the whole Universe. We can all agree that such a study is highly ambitious. To claim, however, as many supporters of big-bang cosmology do, to have arrived at *the* correct theory verges, it

seems to me, on arrogance. If I have ever fallen into this trap myself, it has been in short spells of hubris, inevitably to be followed by nemesis. Our efforts to understand the whole Universe should, it seems to me, be viewed in the way, some seventy years ago, we village boys set about raiding in September the ripening orchards of the larger houses of my home district. If we could get away with it, well and good. But, if we were caught and punished, we had only ourselves to blame.

It is the crowning achievement of science that its entire spectrum can be shown to be derivable from just one broad stream of argument, a stream that began as a trickle in the early nineteenth century due to the work of the French mathematician Joseph Louis Lagrange. The method is concerned with calculations involving a finite volume of space-time—but *any* volume you care to choose. This generality is crucial, for it gives universality to the laws of physics that emerge from the resulting calculations. It is this essential breadth of vision that is lost in the big bang, and it is lost in a very flagrant way. Einstein's famous work on the theory of relativity was founded on the principle that the laws of physics should not depend on how the points of space-time are catalogued by means of what is called a coordinate system. Yet this is just what the big bang does. It catalogues space-time in a particular way and then says that, with respect to its particular choice of coordinates, the broad stream of physics holds, or does not hold, according to a particular division in the catalogue, a division that depends on its own arbitrary mode of construction. Stated more conventionally, in a particular coordinate system, there is a time before which the laws of physics do not hold and after which they do.

It was this artificiality that led Hermann Bondi, Tommy Gold, and me to begin thinking, in 1946–1947, about alternatives. We saw that alternatives would require the creation of matter, and we were at first repelled by the idea. However, the events of the cold winter of 1946–1947 fell out such that I found myself returning to it. I saw that, to make mathematical sense of it, I had to suppose the existence of a so-called scalar field, which turned out to have properties that greatly surprised me. Much of my surprise was due to not really thinking through what happens in everyday physics when some local process releases energy—say, the burning of a pile of wood. We are well used to the loss of energy that occurs as the wood becomes oxidized, the balance of the energy being emitted as light and heat. The light and heat may be absorbed by our surroundings, but, to the extent that they are, our surroundings then reemit the energy. Perhaps, after several such absorptions and reemissions, the energy ultimately goes out into space, emitted by the Earth along with the much larger amount of energy that the Earth receives from the Sun. And it is



there that we normally think the sequence of processes ends, as it would if the Earth were alone in flat space-time. But, in the actual Universe, the energy is ultimately absorbed by the Universe itself. It goes into making a slight change in the rate of expansion of the Universe.

The same thing happened when I investigated the properties of the scalar field, which I called the C-field because I was interested in the possibility of the field serving to create new matter. Creation required energy. It took in energy—the opposite to a wood fire, which gives out energy. The resulting C-field went out from the region of creation, eventually to lose itself in the expansion of the Universe, energy being balanced at all stages.

What puzzled me at first in my investigations of January 1948 was the sign of the effect. It shouldn't have done so, since I had supposedly learned all about signs in standard relativity theory as long ago as my final undergraduate year of 1936. But it may be that, like me, quite a few scientists have the sign wrong in their heads. Thinking of the case of the wood fire, does the positive energy going out from the fire have the effect of slightly speeding up the expansion of the Universe, or does it slightly slow down the Universe? I will just bet that many would say that the fire speeds up the expansion, which is wrong. Positive energy going out with a positive pressure slows the Universe, no doubt about it. This is what Einstein's theory says. We tend to get the sign of the effect wrong through thinking of the explosion of a local cloud under everyday conditions. Internal heat and light do go into speeding the expansion in that case. For the Universe, it is the opposite; and, with the C-field carrying *negative* pressure effects to compensate for the positive energy of newly created particles, the reaction on the Universe was to cause expansion, not to check it. To get the situation right, think of expansion as a *negative* form of energy; then everything follows the right way round.

In 1948, I had no physical ideas about the details of creation. Such ideas were only to come slowly over succeeding years. So, in place of physics, I made a mathematical hypothesis. I assumed matter to be created everywhere at some slow rate, which I visualized as adjustable, as one might adjust the flow of water from a tap. Subject to this hypothesis, I was able to prove what hit me as a remarkable result—namely, that the rate of expansion of the Universe always came into balance with the flow from the tap. Turn up the tap, and the Universe speeds up; turn down the tap, and the Universe slows. Now I felt I understood *why* the Universe was observed to be expanding: it was because matter was being created everywhere.

Let me insert a bit of a diatribe against the big bang at this point. Why, in the big-bang view, does the Universe expand? Think first of a large local

cloud of gas set (by some unspecified agency) in outward motion. If the motion is too weak, the self-gravitation of the cloud will cause it to slow down until it comes eventually to rest and then falls back on itself. If the initial motion is too strong, the self-gravitation of the cloud will not be able to slow it much and the cloud will disperse completely, with all its particles still moving outwards at high speed. Like balancing a pencil on its point, there is an intermediate situation with the cloud neither falling back on itself nor dispersing at high speed. The initial motion is so finely adjusted that the cloud just—and only just—manages to disperse. A little less initial energy, and the cloud would fall back; a little more, and it would disperse too rapidly. This picture of a local cloud generalizes to the big-bang view of the Universe, in which the entire Universe originates like the pencil balanced on its point. The balancing must be ultrafine. The density range in the cloud from the first moment contemplated in the theory ($10^{-43}$ seconds after the supposed origin of the entire Universe) until the present is so vast that the pencil has to be balanced to an accuracy of about 1 part in $10^{60}$. Written out in full, 1 part in 1,000,000,000,000, 000,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000. How is this incredible balance achieved? There is no answer from the big-bang supporters, except with the implication of divine adjustment.

So, with the C-field, I now had an escape from this dilemma. I had a mathematical law that forced a balance between the rate of expansion of the Universe and the density of the matter that it contained. There was no need for an initial situation balanced to infinitesimal accuracy. The situation could start quite out of balance, and, as time went on, it would come increasingly into balance. And I didn't need any appeal to a moment of origin for the Universe. The Universe could be as old as you like.

It was just such a result as a young man on a small salary and with a family to support dreams about, and you can safely assume that I set about writing a paper on it with the utmost dispatch. But I had a heavy teaching load in February 1948, with the university working a six-day week. On good days, I would be finished in time to catch the 4:00 P.M. school bus from Cambridge to Great Abington—these were the days when we were living at Ivy Lodge, the house without electric power. Central heating in a cold winter was not even a vision for the future. The house had a pleasant drawing room with an open fire. With coal supplies minimal, this was the one fire we allowed ourselves, managing elsewhere with portable kerosene stoves. The work went in a rush towards the end, and one night I told my wife that I was going to stay up after the family were abed until the paper was finished, which it was at about 2:30 A.M.

I am unhappy to think that I must have proselytized for my paper. Otherwise, I fail to see how I could have given a seminar on it already by



the first of March. The seminar was in the Cavendish Laboratory, with Paul Dirac in the front row. So, too, somewhat surprisingly, was Werner Heisenberg. I happened to be in Germany the following year, and I was flattered to be told that, on his return, after spending six months at St. John's College, Heisenberg had said that the C-field interaction between the creation of matter and the expansion of the Universe, the negative-pressure effect, was the most interesting idea he had heard during his stay in England.

Hermann Bondi and Tommy Gold were there too at the Cavendish seminar, and they immediately came up with an interesting further idea. The model I had described was for the creation tap to be turned on uniformly everywhere, giving a Universe that, on a large scale, was the same at all times. Bondi and Gold argued that, by observing a relatively small sample of such a Universe, one would know what the entire Universe was like everywhere, not just from place to place but also from time to time. Hence, astronomical observations made at a great distance, at the limiting range of very large telescopes, should (red-shifting effects apart) reveal the same state of affairs as very much more local observations. And, since the latter could be done with relatively modest equipment, it followed that a great deal could be learned about the distant Universe without the need to make huge investments in immense equipment, such as the 200-inch telescope that was coming into commission on Palomar Mountain at just about that time. The position, as Bondi and Gold advanced the argument, was wonderfully hopeful for astronomical observers. It was wholly different from the big-bang theory, in which the observer has no hope at all of penetrating to the supposed origin of the Universe, even if the entire productivity of the human species were expended on it.

But, between us, we had given too many hostages to fortune. To see my way through the mathematics, I had assumed a uniform creation tap, while Bondi and Gold had contracted to explain everything, no matter how far distant, in terms of what was known for galaxies and other astronomical objects within the nearest few tens of millions of light-years. This was a citadel it was going to prove very hard to defend.

Actually, we did quite well for five years or more. Attempts by observers to carry the day against the theory ended for a while in defeat for the observers. But one or two remarks, made to me privately, raised apprehensions that at least had the effect of preventing hubris from appearing onstage. The theory required new galaxies to be formed and at such a rate as to renew the entire distribution of galaxies in a time of the order of 10 thousand million (that is, 10 billion) years. Big-bang cosmology does the same. But big-bang cosmology contrives, as it does in every aspect of astronomy and astrophysics, to make the process of the origin of galaxies

unobservable, whereas our theory required the origin to be very observable. But it wasn't observable, Walter Baade told me; and, in the mid-1950s, my friend Allan Sandage insisted that distant galaxies were slowing down in their expansion rate, whereas, according to our theory, they should have been accelerating.

Walter Baade was kind enough not to make his criticism very public. Nevertheless, I knew it was seriously meant, and it has not been until recent times that I have seen how to answer it in a satisfactory way. A reply to Sandage's criticism was already apparent at the time, however. It was that, in comparing galaxies at different distances, it was possible that like was not being compared with like. This issue has never really been settled to everybody's satisfaction. Only two years ago (1992), at a meeting of the German Astronomical Society, I found cosmologists who take much the position I took in 1955. Meanwhile, I have swung towards Sandage's old view, only to find him less sure about it today than he was twenty-five years ago.

The troubles for the theory that began in the mid-1950s, and that became more severe as time went on, permitted Bondi, Gold, and me to blame each other. I could say, and did, that they had made the scale of their representative local region too small. I thought it should have been 1000 million light-years instead of a hundred million. Actually, it should have been much bigger still. But the worst mistake was my own: my obstinacy over the creation tap, which I kept always open and at a slow trickle. This has turned out to be as wide of the mark as it could be. The correct position is that the tap is nearly always closed; but, on the rare occasions when it opens, a flood emerges. I had plenty of warning. In 1950, my wife and I toured Switzerland in our papier-mâché DKW. I gave a talk at the Technische Hochschule in Zürich. Wolfgang Pauli was there, and, at dinner with him that night, he raised just this question, saying: "If you could understand the physics of how creation happens, it would be much better." Unfortunately, it was to be a long, long time before I came to grips at last with this central issue of the theory, not until I returned to cosmology in 1985, after many years away from the subject.

Because the C-field is a so-called scalar, a quantum description requires it to be made up of bosons, particles with properties analogous to the quanta of an ordinary radiation field. From this, it is to be expected that interaction processes with matter, including the creation process, will be analogous to radiation processes. The latter, being well known, provide a useful catalogue of reference for thinking about the creation process from the quantum point of view, as Wolfgang Pauli was suggesting. The nearest analogue is the process that leads to the strong emission of radiation from a laser, which process leads to conclusions that are very much



in agreement with a wide range of astrophysical observations, all those observations that relate to what is often referred to as high-energy astrophysics—strong radio emission, x-ray emission, active galactic nuclei, and quasars.

A laser is a device in which a number of light quanta combine to induce the downward transitions of atoms, with more quanta coming out than go in, at the expense of the downward transitions of the atoms constituting the material of the laser, which atoms must first be "pumped up" to a higher level before the laser can be triggered. But, for the C-field, there is an important inversion of sign to consider: the inversion of sign that produces expansion of the Universe through a negative pressure, an inversion that causes matter to go up in energy at the expense of the negative effects in the C-field. Technically, this inversion is not hard to achieve. In terms of the method developed by Richard Feynman for describing mathematical interactions of an ordinary radiation field, a function written as $\delta_+$ appears in the quantum amplitude for the process in question, while a time-inverted function $\delta_-$ appears in the complex conjugate of the quantum amplitude. For the C-field, the two functions $\delta_+$ and $\delta_-$ are simply interchanged. My trouble, in 1948, was that I didn't know all this, for the understandable reason that, in 1948, it hadn't yet been done—nor had lasers yet been invented.

A laser is triggered by fine tuning between the frequency of the quanta responsible for the firing and the frequency associated with the transitions of the pumped-up atoms constituting the laser material. In a like manner, the creation of matter is triggered by a fine tuning of the C-field quanta and the frequency associated with the mass of the newly created particles. Now even if such a fine tuning existed initially, it would be lost very soon indeed, when viewed on a cosmological time scale, because the frequency associated with specific particles remains unchanged, whereas C-field quanta in extragalactic space have their frequencies progressively lowered by the expansion of the Universe. So it can be seen now that my guess of 1948—a guess made for mathematical convenience rather than from physics—was a mistake. The tap cannot dribble everywhere at a constant rate. In extragalactic space, it cannot dribble at all. The C-field quanta there must be too low in frequency.

But light quanta gain frequency if they fall into a gravitational field, and so it must also be for C-field quanta. And, if the gravitational field is sufficiently strong, such a rise (for those C-field quanta that happen to fall into it) will become sufficient to open the creation tap. The flood of particle creation generated by the analogy to laser action is then triggered. The existence of the C-field is hypothetical, essentially forced in order to understand how matter came into being. It is essential in order to avoid

the breakdown of physics that otherwise occurs at the supposed big bang. Granted the existence of the C-field, its physical properties can then be formulated in the manner I have just outlined, leading to the view that, whenever sufficiently condensed aggregates of matter are formed, the creation tap is opened. Large negative pressures are generated with the same expansionary effects ensuing as occur cosmologically. A falling together of matter, towards what is called a black hole, is the process that triggers matter creation, and it is a process that causes any aggregate that approaches a black hole too closely to self-destruct, to blow itself apart, the energy of the explosion being compensated by an expansionary push on the Universe.

At this point, observation takes over—or, more properly speaking, should take over. In recent years, what might be called a black-hole establishment has arisen, composed of individuals who talk to each other in positive language, as if black holes were as certain of existence as tomorrow's sunrise. Yet there is not a scintilla of observational evidence to support their position. What there certainly is evidence of are highly condensed aggregates of matter producing very strong gravitational fields. There is a great volume of evidence of violent activity associated with such aggregates, but the evidence is all of outbursts, never of the continuing infalling motion that would lead to the formation of a black hole. The evidence is all of a process that self-destructs. Tommy Gold has described the psychological process whereby people meeting often enough among themselves can become swayed towards quite erroneous conclusions, in a way that the solitary thinker would be proof against. The process is the same as the one whereby whole societies become sucked into amazing misjudgments, as happened in extreme form in the South Sea Bubble and in the astonishing episode of Dutch Tulip Mania. It is a process whereby assurances from others take on the appearance of reality. Once established and running, the process even overrides sharply contrary evidence—for a while, at any rate.

The picture that now opens out is greatly changed. Instead of being locked into a never-ending sameness, as it had been with my mathematically imposed condition of 1948, there is now a wonderful freedom, with the highly condensed aggregates of matter, taken on a wide scale, connected to the rate of expansion of the Universe. Let there be a high average density of aggregates, all blasting away, and the Universe expands rapidly. Let the aggregates disperse through self-destructive explosions, and the Universe slows under its own self-gravitation, perhaps even falling back in on itself.

Now it is a property of the C-field that, quite apart from its relation to the creation of matter, it cannot be compressed indefinitely. The negative



pressure within it eventually rises more rapidly than self-gravitation, with the consequence that an imploding Universe, or an imploding local object, is eventually halted in its inward motion. Thereafter, the motion is reversed, and expansion is repeated. That is to say, without creation, the C-field acts to produce an oscillatory motion. Oppositely, with a great deal of creation, the oscillatory tendency is overwhelmed by expansion. And with a modest degree of creation, the Universe oscillates, but it becomes a little expanded at each oscillation. Broadly speaking, this, I believe, is the path to be followed—at any rate, it is the model best suited to the general time range in which we happen to live. To put it in numbers, each oscillation takes about 40 billion years to complete, 20 billion years from minimum to maximum and 20 billion years back from maximum to minimum. And, becoming a little larger at each oscillation, the Universe doubles its scale in about 20 oscillations—which is to say, in about 800 billion years. The situation is freed from the claustrophobia of the old mathematically constrained model that I suggested in 1948, and it is immensely farther-ranging than the big bang.

Much as I have always disliked the big bang, there is a sense in which one of its concepts survives in the properties of each individual particle of matter during the fleeting moment of its creation. A Machian formulation of general relativity, which Jayant Narlikar and I proposed in 1964, with its scale-invariance and its proof that gravitation must always be attractive between particles of matter, shows that newly created particles have the special property that their Compton and gravitational radii are comparable with each other. Such particles were first conceived of by Max Planck, and so are conveniently referred to as Planck particles. They are much more massive than ordinary particles, about 5,000,000,000,000,000,000 times more massive than a hydrogen atom. Their investigation represents the ultimate aim of the experimental physicist. But such a goal lies far beyond the capability of any equipment that can at present be contemplated as a practical construct. Planck particles are believed to decay into subsidiary particles in a time of about $10^{-40}$ second, with the subsidiary particles then decaying in a progressive cascade that ultimately yields a shower of the much less massive particles with which we are more familiar. This is in a time scale ranging from $10^{-24}$ second to $10^{-10}$ second. It is because the big-bang Universe is believed to have begun as a sea of Planck particles that physicists have become interested in cosmology. But the same is the case for the theory discussed here. Each particle, at creation, is like a big bang in itself, its physical properties as it decays having similarities to the earliest moments of the supposed big bang. Thus, whatever attraction the big bang may have for physicists is paralleled here. The situation is indeed improved from the physicist's point of

view, since the particles he seeks are no more distant in the Universe than the nearest astrophysical high-energy source, whether an active galactic nucleus, a quasar, or a radio source. The supposed big bang, on the other hand, is beyond the range of observation, and, as the young Paul Dirac used to tell us students in the 1930s, "That which is not observable does not exist."

The difference between the present picture and the situation of the 1950s is that the theory is no longer tied to an immensely fast creation rate. It now takes 800 billion years for the Universe to double in scale, not the 10–20 billion years proposed in the 1950s, which cuts the needed creation rate by about 50. The rate at which nearby galaxies are required to form is also cut by 50, which is why Walter Baade insisted that observation simply would not permit the excessively fast rate that seemed then to be required. There is also the difference that, when the astronomer measures the expansion rates of the galaxies, it is the properties of the oscillations that occupy his attention, because the oscillations are fast, masking the slower overall expansion of the Universe. And, if one lives in the expanding half of an oscillation, as we are required to do, the Universe will decelerate as it comes towards maximum phase. It was this deceleration, it seems to me, that Allan Sandage found in the mid-1950s.

But, if the oscillations are averaged away over a very long time scale, it is the slow overall expansion of the Universe that remains, and this has the properties that Hermann Bondi, Tommy Gold, and I claimed it to have—except that everything happens far more slowly than we supposed. Ages are also greatly affected. Our galaxy is more like 300 billion years old than the usually claimed 10 billion years, which explains a lot of persistent trouble that astronomers have had over the estimation of ages. It also explains where the so-called "missing" dark material has gone and why galaxies, especially of the elliptical kind (which are the oldest), are exceedingly inefficient emitters of starlight. Stars like the Sun, which are reasonably efficient producers of light, are of recent formation, belonging indeed to the last 10 billion years or thereabouts. The stars of 300 billion years ago have long since gone, if they were at all efficient. Their products are essentially dead, as far as the production of light is concerned. Otherwise, the remaining stars of 300 billion years ago are faint so-called brown dwarfs, which are barely perceptible because they emit so little light.

The tall, charismatic Martin Ryle, from the Cavendish Laboratory, was the first to state openly that the steady-state theory of Bondi, Gold, and Hoyle was wrong. This was in the second half of the 1950s, at a time when nobody knew anything definite about the nature of the majority of



radio sources. Ryle's idea was to count radio sources in the following way, much as Edwin Hubble had done for galaxies twenty years before. A flux level, $S$, was defined, and then, over a specified fraction (about a third) of the sky, an attempt was made to count the number, $N$, of sources with flux levels greater than $S$. The process was repeated for a number of values of $S$, leading to the determination of $N(S)$ as a function of $S$, a function that was then plotted logarithmically in what was called a log $N$–log $S$ diagram. It can be shown that, statistical fluctuations aside, such a counting process carried out for any standard kind of object in flat Euclidean space-time results in a straight line of slope −1.5 in the log $N$–log $S$ diagram. The theory of Bondi, Gold, and Hoyle led to the same slope of −1.5, provided the objects were not very far away. They could be outside our galaxy, but not a thousand million light-years away or more; otherwise, the slope would be less: −1.4, say, or −1.3.

Between 1955 and 1960, Ryle carried out three such investigations. There was what he called the 2C survey (C for Cambridge), which, he claimed, yielded a slope of −3 or more, and which, therefore (according to him), ruled out our theory. But the 2C survey had so few sources in it that it was seriously affected by statistical fluctuations. The next survey, the 3C, had about 250 sources, and it was said to give a slope of −2 or somewhat steeper than that, and, once again, Ryle claimed that his result ruled out our theory. We, in our turn, argued that, if the slope could change, through statistical fluctuations or observational inaccuracies, from being −3 to −2 in only a year or so, then, in a further year or two, it might become −1.5 or even less. Ryle's third shot was called the 3CR (R for revised) and it was said to give a slope of −1.8.

The negative slope meant that, as $S$ decreased, $N$ increased, and the steeper the slope, the more $N$ increased. Thus, a slope of −1.8 had a steeper rise of $N$ as $S$ decreased than a slope of −1.5. Now, in such a situation, a steeper slope could mean either an excess of $N$ at smaller $S$ or a deficit of $N$ at larger $S$. If the latter, the deficit of sources of large $S$ in Ryle's 3CR survey needed to be only a handful, again making his claim statistically dubious.

The stage was thus set when, in early 1961, I had a telephone call from the headquarters of the Mullard Company. The Mullard Company had made extensive donations to radioastronomy at the Cavendish, so much so that the radiotelescopes at Lord's Bridge on the Barton Road had become known as the Mullard Observatories. A polite voice informed me that, during the coming week, Professor Ryle would be announcing new, hitherto undisclosed results that I might find of interest and asked if my wife and I would care to accept an invitation to be present. So it came about that, in the afternoon a few days later, I turned up with my wife at

the Mullard headquarters in London. A smartly dressed Mullardman of about my own age led us into a modest-sized hall in which a number of media representatives were assembled. We were escorted by our host to the front row, where my wife was bowed into a seat. Then I was led on to a raised dais and bowed into a chair, not so comfortable as the one my wife had just been given. The smartly dressed man then withdrew, leaving me to gaze down on the media representatives. The rest of the stage decor consisted of a blackboard on an easel, a lowered screen for slides, and, I believe, a lectern.

So what was I to think about as I sat there under the bright lights? It needed no great gift of prophecy to foretell that what I was about to hear would have something to do with the log $N$–log $S$ business. But was I being uncharitable in thinking that the new results Ryle would shortly be announcing were adverse to my position? Surely, if they were adverse, I would hardly have been set up so blatantly. Surely, it must mean that Ryle was about to announce results in consonance with the steady-state theory, ending with a handsome apology for his previously misleading reports. So, I set about composing an equally handsome reply in my mind.

A curtain parted, and Ryle entered. The Mullardman made a short introduction, and, pretty soon, Ryle had launched not into the promised statement but into a lecture. I was well used to its form, so I sat there, hardly listening, becoming more and more convinced that, incredible as it might seem, I really had been set up. The results involved the sources of what were now called the 4C survey. The 4C survey contained more sources than before, Ryle explained, greatly reducing statistical fluctuations. Yet the slope of −1.8 had been maintaining, showing that the steady-state theory was wrong, and would Professor Hoyle care to comment? The media leant forward in anticipation.

David Bates, with whom I had worked on the Earth's ionized layers circa 1948, had a story of a serious-minded academic sent by the Foreign Office to Germany, after the Second World War, to deliver elevating lectures to the troops, both British and American. An American C.O., having by then had enough of elevating lectures, introduced the serious chap to his men with a wide sweep of the arm, exclaiming, "He's the British Bob Hope! Boys, he'll slay ya." I know just what the academic must have felt, because that was the way I felt that day.

Ryle's supposed demolition of the steady-state theory was the lead story on the front pages of the London evening papers that night. For the next week, my children were ragged about it at school. The telephone rang incessantly. I just let it ring, but my wife, fearing something had happened to the children, always answered, fending off the callers.

The publicity had one good effect, however. Thereafter, the problem passed into hands more competent than those in the Cavendish Laboratory, at first with Bernard Mills, under the aegis of the ferocious Harry Messel in Australia. Knowing Harry, I think that, had he been in my position at the Mullard place, he would have been likely to have turned up with a hunting rifle and would have been prepared to use it liberally. What was eventually found was that the sources of the 4C and later fainter surveys have a slope in the log $N$–log $S$ diagram that is little different from −1.5, except over a quite small range of $S$, a factor in $S$ of about 3, where indeed there is a mysterious steepening of the radio-source count.

If the radio sources had turned out to be not very far away, the problem would probably have stopped at that point, since comparatively nearby sources behave as if they were in flat Euclidean space for which the log $N$–log $S$ slope should indeed be −1.5. The discovery of a steeper slope over a small range of $S$ would have been seen simply as a fluctuation of no particular cosmological consequence, and that would have been the end of it. But, as the years passed by, and explicit identifications of radio sources with explicit galaxies became more and more available, it gradually appeared that very large distances were actually involved, for which the Euclidean behavior in the log $N$–log $S$ diagram apparently should not apply. Yet it did, more and more, as counts were made to lower and lower flux values. The counts made it look as if space-time were flat Euclidean—at any rate, to flux values, $S$, that were only a tenth as large as those that were available at the Mullard meeting.

The big-bang theory explains this remarkable result as a matter of happenstance. Radio sources change intrinsically with time and they just happen to do so in a way that compensates essentially precisely for the effect of the expansion of the Universe, so that, in combination, the situation mocks a Euclidean state of affairs. And nobody knows why. This would be bad, but what makes it worse is that the same thing has to happen for the apparent angular sizes of the radio sources. By happenstance, and without any apparent connection to fluxes, the sizes of radio sources must change with time in such a way as to mask the effect of the expansion of the Universe, again mocking a Euclidean structure for space-time. These are two examples of the large number of hypotheses that the big-bang theory must make in order to save itself. Instead of the theory serving to make deductions that can be compared with observations, as in normal science, the "theory" is really a catalogue of hypotheses, like a gardener's catalogue.

The explanation of the Euclidean puzzle turns out to be simple, in the theory stated above. Going backwards from oscillation to oscillation, radio sources that are uniformly distributed and intrinsically similar to each other can easily be proved to increase in $N$ as $S$ falls with increasing dis-

tance, just as in the Euclidean case, as $S^{-3/2}$. It is only when the cycles go back far enough, some ten cycles or more, with the slow overall expansion of the Universe becoming important, that the slope falls off, with $N$ then increasing less rapidly than $S^{-3/2}$. The steep slope over a small range of $S$ turns out to be caused by a discontinuous jump from the present half cycle to the previous cycle. It turns out to be all very straightforward, without any element of happenstance being required. The ultimately remarkable outcome, from the point of view of the radioastronomer, is how amazingly far back in time the log $N$–log $S$ observations reach. Back to the eventual fall-off of slope, some 15 cycles of oscillation are involved. With 40 billion years occupied per cycle, this is a look-back age of about 600 billion years, much farther back than is achievable by any of the usual forms of astronomy, and, of course, vastly further back than the hypothetical big bang permits the Universe to exist.

In the late 1950s, it was found in the laboratory that a curious kind of particle forms when metallic vapors are cooled slowly, a particle shaped like a long, very fine needle. Typically, the lengths are a fraction, perhaps a third, of a millimeter and the diameters are about a hundred-thousandth of a millimeter. The first thing I did, when I returned to cosmology in 1985, after an absence of 15 years, was to calculate the electromagnetic properties of such particles: I found that they have immensely strong absorption and emission properties for radiation with wavelengths in the so-called microwave background, a background that had been discovered by Arno Penzias and Robert Wilson in 1965 and that is supposed by many to prove the correctness of big-bang cosmology.

Chandra Wickramasinghe checked and improved my calculations by high-speed computer, and it was the circumstance that particles known to exist in the laboratory have the ability to produce microwave radiation in a perfectly normal, everyday way that first made me acutely suspicious of the claim that only through the origin of the Universe in a big bang can the microwave background be explained. Add, too, that the laboratory condition of the slow cooling of metallic vapors is closely imitated in the cooling of metals produced by supernovae, that supernovae tend to occur in associations of massive stars, which, in concert, over relatively short periods, expel their material at high speeds, not only into their parent galaxies but out of them altogether into extragalactic space, and it was apparent that the means for producing the microwave background by straightforward astronomical means were all in place.

Even so, until I began collaborating again with Jayant Narlikar and my old friend Geoffrey Burbidge, I didn't appreciate just how easy and straightforward it was going to be. It was merely a matter of using intergalactic iron needles, of which no great density is needed, to degrade starlight into microwaves—which is to say, radiation with wavelengths generally in the region of one millimeter. To put it in numbers, we know that, over about 30 percent of an oscillatory cycle of the Universe, the cycle in which we are presently living, stars have produced about $2.10^{-14}$ erg of energy for each cubic centimeter of extragalactic space. Hence, over some 15 similar cycles—the time for the slow doubling of the scale of the Universe—the energy produced would be about $10^{-12}$ erg for each cubic centimeter of extragalactic space. Or it would be, if the slow expansion of the Universe were not taking place. The latter spreads the energy somewhat, reducing the concentration to about $4 \times 10^{-13}$ erg for each cubic centimeter of extragalactic space, and this, after being absorbed and reemitted many times by the iron needles, can readily be shown to generate a black-body radiation distribution with a temperature of 2.7 kelvins, which is just the observed value for the microwave background. It is also easy to show that the resulting black-body distribution would be exceedingly homogeneous and isotropic, with temperature fluctuations from place to place, and also from one direction to another in the sky, of no more than a few parts in a million, arising from irregularities in the distribution of the sources of the starlight. All the requirements of observation are thus well met, and really without any significant hypotheses having to be made. The stars exist. The starlight is there, and its intensity is known from observation. Iron needles exist in the laboratory. Supernovae as sources of iron exist. All the components needed for understanding the origin of the microwave background quite outside big-bang cosmology are therefore known with certainty, and only relatively easy calculations are needed to put them all together. In astronomy and astrophysics, one cannot do better than that, especially inasmuch as the answer turns out to agree with observation more or less exactly.

How, in big-bang cosmology, is the microwave background explained? Despite what supporters of big-bang cosmology claim, it is not explained. The supposed explanation is nothing but an entry in the gardener's catalogue of hypotheses that constitutes the theory. Had observation given 27 kelvins instead of 2.7 kelvins for the temperature, then 27 kelvins would have been entered in the catalogue. Or 0.27 kelvin. Or anything at all.

Big-bang cosmology is a form of religious fundamentalism, as is the furor over black holes, and this is why these peculiar states of mind have flourished so strongly over the past quarter century. It is in the nature of fundamentalism that it should contain a powerful streak of irrationality and that it should not relate, in a verifiable, practical way, to the everyday world. It is also necessary for a fundamentalist belief that it should permit

the emergence of gurus, whose pronouncements can be widely reported and pondered on endlessly—endlessly for the reason that they contain nothing of substance, so that it would take an eternity of time to distil even one drop of sense from them. Big-bang cosmology refers to an epoch that cannot be reached by any form of astronomy, and, in more than two decades, it has not produced a single successful prediction.

A state of zero progress also suits the world's scientific establishments. A scientific revolution, such as the one that occurred with the arrival of quantum mechanics in 1925, sweeps away the pillars of scientific establishments. Within only two or three years, they are gone, to be replaced by a new generation of young people in their twenties. Today, in a state of zero progress—indeed, with the stately galleon of science even blown backwards—there is little hope for young people in their twenties. They must do what aging gurus tell them to do, which is nothing.

A state of zero progress also favors demands on governments for larger and larger sums of money. Because, on the average, science has repaid society well over the years, scientists as a body hold a kind of blackmail over governments, blackmail that becomes stronger when things are going badly. For then it is possible to blame the becalmed state of science on inadequate financial support. More and more extravagant expenditures on larger and larger machines and instruments are demanded in order to escape from the impasse, whereas, in good times, no such blackmail needs to be exercised. The worse things get, the more scientists meet together internationally in the interest (supposedly) of progress. But, as Tommy Gold points out, perpetually meeting together locks people's beliefs together into a fixed pattern, and, if the pattern is not yielding progress, the situation soon becomes moribund. These considerations provide ample motivation for attempts to preserve the status quo in cosmology: religion, the reputations of the aging, and money. Always in such situations in the past, however, the crack has eventually come. The Universe eventually has its way over the prejudices of men, and I optimistically predict it will be so again.

Religion is a hard problem, one I will attempt to discuss a little by way of ending this book. The crude denial of religion that became prevalent among so-called rationalists in the late nineteenth century was, in my opinion, a response to the social and economic conditions of the time. It had no real intellectual value. And, setting aside also the ancient religions, the first modern statement on religion that I find of interest was that made by James Jeans in the 1920s, that God is a mathematician, although, in this, he was plainly following in the steps of a French mathematician of the early nineteenth century, Pierre Simon de Laplace.



Nowadays, however, I would not accord to mathematics the prestige that I once did. Mathematics consists *only* in saying that quantities are the same—as, for instance, 5, 2 + 3, and 7 − 2 are the same. The latter are what we call "obvious," and making the pronouncement of their equality would confer no prestige on a person who attempted to proclaim them from the housetops. Likewise, all mathematical statements, I believe, would seem obvious at an adequate level of intellect. They seem otherwise to us only because we are not good at mathematical thinking. We have to carry mathematical equalities—theorems, we call them—around in our heads as crutches to our thinking because, collectively, as a species, we are somewhat dim-witted and so cannot instantly perceive what is true, as a superior intellect might do. During the First World War, a young Indian named Srinivasa Ramanujan Ivengar traveled to England to work with the foremost mathematicians at Trinity College, Cambridge. Ramanujan was almost entirely self-taught; yet he had an uncanny ability to say that two entirely different-looking and ferociously complex mathematical expressions were the same. Often, he had no proof, and only occasionally was he wrong. I think it correct that, even to this day, no formally trained mathematician really understands where his perceptions came from. Ramanujan was a hint of what a superior intellect might be able to do. His case was also a hint that genetic possibilities for doing much better than we have yet done may lay, still unexpressed, in the human genome. If indeed a sufficiently superior intellect were able to reduce mathematics to a set of trivia, then James Jeans's description of God as a mathematician hardly seems adequately complimentary. It is as if a crowd of dogs were to attribute divinity to the ability to see that 2 + 3 and 7 − 2 are the same.

Theoretical physics is a different matter. As I now see things, theoretical physics stands intellectually above mathematics. The great discovery of Paul Dirac of the wave equation of the electron will serve again here. A certain operation acting on a spinor field led to a second spinor field. A similar operation on the second field led to a third, and so on, ad infinitum. There is nothing much, I think, that even a superior intellect could do further to this process, so far as mathematics is concerned. But what Dirac did was indeed something further. It was to say that the odd spinors in such a sequence are all the same, as are the even-numbered spinors—the second, the fourth, and so on. Mathematically, this need not be true. What physics does is to make it true, thereby *defining* the Universe. Thus, the Universe is a set of restrictions on mathematical quantities of the kind discovered by Dirac. God—if we are to follow James Jeans—is not a mathematician but rather the chap who thought up the restrictions.

I purposely don't want to make God too remote—nothing like the awe-

some God of the ancient Hebrews—because I don't believe that concept is right, impressive as it may be. I can explain the difference in terms of an old Spanish story. God, in disguise, falls in with a peasant walking on the road and asks, "Where are you going?" To this, the peasant replies, "To Saragossa," without adding the obligatory medieval addendum *Deus voluit* ("God willing"). For this disrespect, God turns the peasant into a frog and flicks him into the nearest puddle. After watching the frog flounder for a while, God reverses the process and says to the peasant, when restored to human shape, "And now where are you going?" To this the peasant replies, "To Saragossa. Or, into the puddle." The angry gods of the ancient world would have had the peasant straight back into the puddle. My God, in contrast, would make quite certain he got to Saragossa. A mistake of all fundamentalist religions is that their gods have no sense of humor. This is because fundamentalist religions are maintained over long periods by ritual, and ritual, in its very nature, has no sense of humor.

By returning to Paul Dirac's discovery, we can see other attributes of God. With the behavior of an electron determined by the equality of the odd spinors (and that of the even spinors), turn now to the solution of the simplest practical problem one can think of, a single electron bound electrically to a proton to form a hydrogen atom. It is natural to human thought—at least to my way of thinking—to imagine the way to choose the constraints that represent the laws of physics would be to ensure that their consequences were as simply derived as possible. But the opposite is the case. The apparently simple problem of the hydrogen atom is one that none of the multitude of textbooks of which I am aware that seek to inform us about the mysteries of quantum mechanics manages to solve fully—except one.* A skilled lecturer would need a whole term of lectures to cover it fully, which is why almost no student knows it. They rush into more complex and seemingly more interesting problems without bothering to make a proper job of the simplest.

The clear lesson, therefore, is that the laws of physics are specified so as to make for exquisite complexity, emphatically not the reverse. The amazing fact to contemplate is that the seemingly simple discovery of Dirac, taken with an elegant principle of symmetry in group theory, determines the whole of chemistry and, ultimately, of biochemistry, ranging up to the astonishing catalytic properties of proteins, on which life depends. It is all in there in the restrictions on the spinors. It is because of this incredible chain of subtlety that I doubt the nineteenth-century denial of a purposive Universe, and also why I doubt the crude breaking of the physical laws that occurs in big-bang cosmology.

*Claude Itzykson and Jean-Bernard Zuber, *Quantum Field Theory* (McGraw-Hill, New York, 1985).

In the days in which I was involved in British science politics, a well-known chemist visited me with the aim of securing my support for a £10 million project, the money to come from the government, as always. What he wanted was to acquire a supercomputer that would work out all of chemistry. Instead of brusquely sending him packing, I had the tact to use universityspeak, which, being very soft, is supposed to turn away wrath but sometimes doesn't. No computer that humans will ever build will work out all of chemistry. Indeed, no computer that humans will ever build will do much more than can already be done with a desktop job costing less than £1000. If you ask what is needed to work out the full consequences of the laws of physics (chemistry, with biochemistry, being a fair slice of it), the answer is, Nothing less than the whole Universe. It is not too much of a guess to say that that is just what the Universe is: the calculation of the effects of the physical laws. This explains a problem that has puzzled theologians, philosophers, and scientists alike: Why is there a Universe at all? The theologian, with his belief in an all-powerful God, wonders why God didn't simply perceive the Universe. Why bother actually to have it? The answer is that the Universe *is* the simplest way of perceiving it. Any attempt to calculate the Universe, as my chemist acquaintance wanted to calculate all of chemistry, would end up with something a great deal more cumbersome. What really can be done in a compass less than the Universe is to perceive highlights, to manage meaningful argument by taking immense shortcuts, but with the loss of a great deal of detail.

In earlier chapters, I mentioned climbing nearly 300 of the Scottish mountains known informally as the Munros. About a half I did alone, as I did with the last one I mentioned in some detail, Blaven. The Munros are not dangerous or difficult, in the technical sense that an Alpine peak may be dangerous, although, if you are of a mind to it, you can find plenty of hard-to-climb rocks, especially on the Isle of Skye. The dangers come, rather, from sudden storms with ice-cold rain, or heavy snow, or unbelievably high winds, combined often with big distances to be made to safety. Inevitably, in being abroad on the mountains so often, I would run into bad conditions, particularly because the most spectacular situations occur in winter, in which I most enjoyed being out-of-doors. Inevitably, too, it became essential to learn survival techniques, of which by far the most important is anticipation. One problem that was difficult to anticipate, however, was the sudden descent of heavy mist. Being suddenly sur-

rounded by what amounted to a thick cloud, in unknown country, far from one's destination, is in many ways analogous to doing scientific research. There are no straightforward paths to follow, and the number of mistakes one can make is legion. The best I could ever achieve was to proceed slowly (crabwise, as it were) with map and compass—for which, in scientific research, you can substitute observation and calculation. Working your way out of an awkward position takes what seems an age, and this too happens in scientific research. When I consider cosmology, as I started out in cosmology in the cold February of 1948, it seems no very great step to the position I hold today. I am perpetually astonished at the slowness with which perceptions come, just as one can scarcely credit the ineffectiveness of one's stumblings on a mountainside in the moment when the mist clears.

A good fraction of those Munros I didn't climb alone were done with my friend Dick Cook, whose ideas for coping with difficulties were much the same as mine—in fact, I learned most of my survival methods from Dick. Occasionally, however, mountains would be climbed in considerable parties—ten to twenty persons, perhaps. Down, on some of those occasions, would come a thick mist, and what happened then? Dick Cook and I would take off our rucksacks, pull out maps and compasses, obtain bearings, and start arguing about what was to be done. Among twenty persons, there was always somebody who knew better, however, someone who would stride away boldly into the mist, proclaiming that he knew to a jot where he was and to a tittle exactly how to proceed. Then the amazing thing happened. The rest of the party always—always, I swear—followed our hero, reminiscent of a song, much favored in my youth, about a dasher who carried a banner with a strange device, a device that, on examination, read nothing but "Excelsior!" I puzzled a lot about that device, but I never arrived at a satisfactory explanation of it.

Dick Cook and I would usually succeed in extricating ourselves from the mist-covered hills and would arrive back at our hotel in time for a bath before dinner. The others would stagger in, hollow-eyed, at later hours running into the early morning, or even into more distant time. Well, in my opinion, this is exactly the way it has been in cosmology during the quarter century or more that has elapsed since the discovery of the microwave background in 1965. And this is just the way it has been in the religions of the world since time immemorial.

The rule, then, is to proceed crabwise, and my problem now is how to proceed crabwise from where I stand today. Sir James Jeans, responsible for the concept of God the mathematician, has been unlucky posthumously. From a wrong mathematical analysis of the stability of stars, he was led to a mistaken view about the properties of stars, and so Jeans has



appeared to leave little impression on astronomical development. But he foresaw the two distinct time scales discussed above, the time scale of order 10 billion years associated with stars and the time scale of 1000 billion years associated with the dynamics of galaxies and with the slow expansion of the Universe in the preceding interpretation. More remarkable still, he was responsible for the following sentence:

> The type of conjecture which presents itself somewhat insistently is that the centres of galaxies are of the nature of "singular points" at which matter is poured into our universe from some other, and entirely extraneous dimension, so that, to a denizen of our universe, they appear as points at which matter is being continuously created.

There now seems to be so much that is correct about Jeans's speculation that, far out as it might seem, we might wonder if meaning can be attached to the concept of "pouring" in from an extraneous dimension, thereby breaking the restriction of the entire Universe to the four dimensions of space and time. There is certainly something unattractive about regarding particle trajectories as beginning in the way that the creation of matter seems to require, so that it would surely be better if we could think of particles as having come from somewhere else.

It is worth considering, for a moment, the phenomenon in physics of pair creation. What happens is that a radiation quantum of high energy disappears in this process, giving rise to an electron plus a positron. To avoid the need for the electron and positron to have a beginning, Paul Dirac conceived of what came to be called "the vacuum," an infinite sea of electrons occupying negative energy states. It is reported that Wolfgang Pauli had a hearty laugh when he heard this notion, claiming Dirac had at last flipped his lid. The trouble for Pauli was that Dirac succeeded in calculating results that agreed with experiments. Dirac added the strange notion of "the vacuum" being unobservable. What the radiation quantum then did was to lift one of the electrons in the infinite sea from its negative state into a positive energy state, where it became observable as an ordinary electron. And the gap in the infinite sea was the positron. This was the way I learned it as a student in 1935–1936; but, in 1949, Richard Feynman gave an interesting alternative way of looking at the matter that is equivalent mathematically to Dirac's result.

With his characteristic originality of mind, Feynman made the positron and electron into essentially one particle, differing only in the sense in which they moved with respect to time. A positron was an electron moving backwards in time, future to past instead of past to future. Or an electron was a positron moving backwards in time. Either way would do.

What a radiation quantum then did when a positron–electron pair appeared was simply to invert the time sense of the positron. Thus, the positron is traveling backwards in time when it encounters the radiation quantum, and the interaction between them turns the particle path around and causes it to move forward with respect to time, when it becomes an electron. We are familiar with particles moving from left to right in space being turned round by a field so as to move from right to left. According to Feynman, it was the same with respect to time. And why not? Time should behave like space.

With this background, we can see a little of the way towards developing Jeans's idea. A particle moving in some extraneous dimension simply has its path turned into our world by the C-field I discussed above. Over many years, I did not take this idea seriously because I was in difficulty to understand why we couldn't see into the extraneous dimension. The mathematical description of the propagation of all fields seems to require that they are able to spread into any dimension that is available, by means of a so-called wave equation that includes all the available dimensions. So for this idea to have any chance of viability, a quite unusual mathematical restriction is needed. All our fields of physics have to be confined to what Jeans refers to as "our universe." It must be the fields rather than the particles that fail to penetrate outside. This is a very strange idea, but, since we have come so far already, it is worth thinking a little further.

In *Walden*, Thoreau wrote: "Our life is frittered away by detail . . . simplify, simplify." Do so by thinking in ordinary three-dimensional space. Collapse down the usual space-time into just two dimensions—say, the horizontal plane—and call it Π. Then the vertical direction is that of the particle paths when they are outside "our universe." And all our usual fields—electromagnetic, nuclear, gravitation—are in Π, where they can only act on particles moving in the vertical dimension in the brief moment when the particle paths cut through Π. The interaction that occurs in this brief moment may, in analogy to the radiation quantum interacting with the positron–electron path, have a probability of turning the particle paths from being perpendicular to Π to being in Π itself. Calculating such a quantum probability would be a formidable problem, but it would be conceivable.

Inevitably, in such a calculation, there would, with the particle in Π and so subject to the usual physical interactions, be a continuing possibility of the path being turned back out of Π, and, therefore, of the particle being returned to the "extraneous dimension." But, if we now play the card of the particle being of the kind mentioned above, a Planck particle subject to decay into a vast number of ordinary particles, such particles can become trapped into "our universe," provided decay can be got in



before the particle slips back into the extraneous dimension. In principle, such a reversal could happen, but, in practice, it never does. So there is the beginning of an idea that can possibly be made to work—provided ordinary physical fields can be confined to Π, that is to say. Additionally, too, one could suspect that it is this trick of the decay of Planck particles that gives a time sense to our Universe, a time sense that is ultimately responsible for all those phenomena that lead to the degradation of ordered structures—as, for instance, hair that goes gray and lines that appear and deepen on the face—and that, in the end, lead to a visit from Shakespeare's fell sergeant, who is strict in his arrest.

Although, at present, this is only a crabwise move, it leads to a position from which I can perhaps explain my principal objections to the religious concept of an all-powerful God. Religions with an all-powerful God make no sense unless you also believe that God is pretty evil, or at least wholly indifferent to bad things that happen. If you believe in an all-powerful God, you have to ascribe to God a morality inferior to that of humans, which is quite a measure of condemnation. But the real point is that God is not all-powerful, God cannot overcome the evils of decay because the issue is not one that is open to choice. If you have the Universe, then you must have decay. If you have no decay, you have no Universe. Take your pick.

I have no particular liking for early Italian religious art. But, by the time religious art attained the standard of Raphael, it assumed an unintended degree of interest, for, when you look at Raphael's madonnas, you know what his girl friends were like. So, too, with Botticelli. And if today you combed the piazzas of Florence, it is a racing certainty that you will find girls essentially undistinguishable from the ones that Raphael and Botticelli painted. The phenomenon of life is an immensely clever way to beat decay, and, if a further solution to the problem of "I am me" can be found, the solution is complete.

Today we have the extremes of atheistic and fundamentalist views, and it is, in my opinion, a case of a plague on all their houses. The atheistic view that the Universe just happens to be here without purpose and yet with exquisite logical structure appears to me to be obtuse, whereas the perpetual quarrelings of fundamentalist groups is worse than that. Not all the religious quarrels I ever saw or read about is worth the death of a single child.

One can conceive of various Universes defined by different forms of mathematical restrictions. What I suspect is that the restrictions defining "our universe" are not just any old restrictions. The restrictions are optimized for their consequences. Or, to put it another way, God is doing His best, and to load off onto Him the all-powerful concept is a gross

insult, an insult by people who do not merit the great trouble that has been taken on their behalf.

To return to crabwise possibilities: If Jeans was right in his postulate of an extradimensionality outside Π, then it is another racing certainty that there must be the possibility of communication existing in some way between Π and what is outside Π. By what has been said, the communication cannot be through the familiar fields of physics. It would need to be something else. This is a platform for the religious person to jump on. This is how to communicate with God, it might be said. Perhaps by prayer. It could be so, but I would prefer something less exposed to the accusation of self-deception. Better, it seems to me, to go for something we can all agree about. It could be consciousness. Consciousness is an experimental fact. More strongly than that, even; without consciousness, there would be no experimental facts. There would be no science, nothing but a nightmare puppet world. It is surely strange that science, utterly dependent on consciousness, should have little or nothing to say about it. With consciousness going outside Π and with science hitherto confined to Π, we can perhaps at last see why.

It is the nature of interactions that they have two ends. Our bodies, our brains and nervous systems, are clearly one end. But what is the other? At a crabwise guess, I suggest a grand information center. To be biblical again, it is said that God sees every sparrow that falls. Well, if He does, it is because we report it. It is because each of us, and every other animal in some degree, and every suitable aggregate of hydrogen, carbon, nitrogen, oxygen, and so on, anywhere over the whole Universe, is an agent, reporting back what we see and experience. Only in this way can I seem to make the beginnings of sense of what is going on. At present, it is but a speculation, but, come another thousand years of understanding, it may not be.

To continue to make sense, I have to suppose that something of a trick or illusion is practiced on all of us. We all have the impression that it is our individual end of the two-way channel that matters, whereas, surely, if the idea is correct, it must be the other end. The trick I can conceive of as being necessary to keep order among an immense number of channels (rather as, in a telephone system, individual conversations must be kept separate from each other). But we have clear clues that our incessant concern with self, with *me*, isn't right. I have remarked before that, after the extraction of a tooth, I have never felt the slightest warmth of affection for the thing. Most dentists know it, and they don't even bother to show the tooth to the patient. I suspect that the same holds for the rest of our bodies, which, like the tooth, are fine so long as they continue to work. And I suspect that, like the tooth, which certainly isn't *me*, neither are our



bodies. Our impression otherwise is the trick, the illusion necessary, I suppose, to keep the two-way link operative. But it surely must be the other end that is somehow associated with *me*. It might seem a big plus mark to see one's way through this problem, but I suspect that things might not work too well if we could. After a lifetime of crabwise thinking, I have gradually become aware of the towering intellectual structure of the world. One article of faith I have about it is that, whatever the end may be for each of us, it cannot be a bad one.